CLAIMS

1. Apparatus for forming a hole in a region of the heart muscle wall of a patient undergoing myocardial revascularization comprising:

means for removing tissue from the region to form the hole;

a light source that illuminates the region with light that generates photoacoustic waves therein;

at least one acoustic sensor that generates signals responsive to the photoacoustic waves; and

a controller that receives the signals and processes them to determine a characteristic of the region useable to control the means for removing tissue.

2. Apparatus according to claim 1 wherein the light source illuminates the region with at least one pulse of light at a wavelength at which light is absorbed by a substance in the region whose concentration can be used to assess a degree of ischemia in the region and wherein the controller processes the signals provided by the at least one acoustic sensor to assay the substance.

3. Apparatus according to claim 2 wherein the substance is hemoglobin.

4. Apparatus according to claim 3 wherein the hemoglobin is oxygenated.

5. Apparatus according to claim 2 or claim 3 wherein the substance is cytochrome aa_3 redox.

6. Apparatus according to any of claims 1-5 wherein the light source illuminates the region with at least one pulse of light at a wavelength at which light is absorbed by water and determines temperature of the region responsive to the signals.

7. Apparatus according to claim 6 and comprising a heat pump that generates a temperature difference between tissue in the region and an ambient temperature of the heart wall and wherein the controller thereafter determines temperature of the tissue as a function of time to assess a degree of ischemia in the region.

8. Apparatus according to any of the preceding claims wherein the light source illuminates the region with at least one light pulse prior to forming the hole and the controller processes the signals to determine a thickness of the heart wall in the region.

9. Apparatus according to any of the preceding claims wherein after onset of formation of the hole the light source illuminates the region with at least one light pulse that illuminates the bottom of the hole and the controller uses the signals generated by the at least one acoustic sensor to determine a depth for the hole.

10. Apparatus according to claim 9 wherein the controller controls the means for removing tissue from the region responsive to the determined depth and stops formation of the hole by the means for removing tissue when a desired hole depth is reached.

11. Apparatus according to any of the preceding claims wherein the hole is formed in a first surface of the heart wall and deepened towards a second surface of the heart wall and during formation of the hole the light source illuminates the region with at least one light pulse that illuminates the bottom of the hole and the controller uses the signals generated by the at least one acoustic sensor to determine a thickness of the heart muscle wall between the bottom of the hole and the second surface.

12. Apparatus according to claim 11 wherein the first surface is an inner surface of the heart wall.

13. Apparatus according to claim 11 wherein the first surface is an outer surface of the heart wall.

14. Apparatus according to any of claims 9-13 wherein the controller controls the means for removing tissue from the region responsive to the determined thickness and stops formation of the hole by the means for removing tissue when a desired thickness is reached.

15. Apparatus according to any of the preceding claims wherein the means for removing tissue comprises a source of ablative energy having an output port from which the ablative energy source provides energy for removing heart tissue by ablation.

16. Apparatus according to claim 15 wherein the source of ablative energy illuminates the region with at least one pulse of ablative energy to form the hole.

17. Apparatus according to claim 16 wherein the at least one ablative pulse generates an acoustic shock wave in the region responsive to which the at least one acoustic sensor generates signals that are transmitted to the controller and wherein the controller processes the signals to determine at least one characteristic of the shock waves.

18. Apparatus according to claim 17 wherein the controller controls at least one characteristic of the at least one ablative pulse responsive to the determined at least one characteristic of the shock wave.

19. Apparatus according to claim 18 wherein at least one characteristic of the at least one ablative pulse is at least one of pulse width, rise time, fall time, peak, and energy and repetition rate of the at least one ablative pulse.

20. Apparatus according to any of claims 17-19 wherein the at least one characteristic of the shock wave is at least one of temporal profile, duration, maximum pressure, minimum pressure, average pressure average intensity and integrated intensity of the acoustic shock wave.

21. Apparatus according to any of claims 16-19 wherein the pulse generates an acoustic shock wave and wherein an acoustic sensor of the at least one acoustic sensor generates signals responsive to reflections of acoustic energy from the shock wave which the controller processes to determine a characteristic of the region.

22. Apparatus according to claim 21 wherein the characteristic comprises a depth of the hole.

23. Apparatus according to claim 21 or claim 22 wherein the characteristic comprises a thickness of the heart muscle wall between the bottom of the hole and a surface of the wall.

24. Apparatus according to any of claims 16-23 wherein the at least one acoustic sensor generates signals responsive to an acoustic shock wave generated by the at least one ablative

pulse and the controller processes the signals to determine location of the source of the shock waves.

25. Apparatus according to any of claims 16-24 wherein the at least one ablative pulse comprises a plurality of ablative pulses.

26. Apparatus according to any of claims 15-24 wherein the light source illuminates the region with at least one pulse of light after onset of ablation and the controller uses signals generated by the at least one acoustic sensor responsive to photoacoustic waves to assess damage to tissue in the region of the hole caused by ablation.

27. Apparatus according to claim 26 wherein the wavelength of the at least one light pulse is determined so as to increase a difference in the photoacoustic response of damaged tissue relative to undamaged tissue.

28. Apparatus according to claim 26 or claim 27 wherein the damage comprises thermal damage.

29. Apparatus according to any of claims 26-28 wherein the damage comprises acidosis.

30. Apparatus according to any of claims 26-29 wherein the controller controls at least one characteristic of the ablative pulses responsive to the determined damage.

31. Apparatus according to any of claims 15-30 wherein the controller processes the signals from the at least one acoustic sensor to determine a distance of the ablative energy output port to the bottom of the hole.

32. Apparatus according to any of claims 15-31 wherein the ablative energy comprises electromagnetic energy.

33. Apparatus according to any of claims 15-32 wherein the ablative energy comprises acoustic energy.

34. Apparatus according to any of claims 15-33 wherein the ablative energy comprises optical energy.

35. Apparatus according to any of claims 15-34 and comprising a catheter having a drill end that is positioned in a neighborhood of or in contact with the region in order to form the hole and wherein the optical output aperture, the ablative energy output port and an acoustic sensor of the at least one acoustic sensor are mounted inside the catheter in a neighborhood of the drill end.

36. Apparatus according to any of claims 15-35 wherein the controller processes signals that it receives from the at least one acoustic sensor to determine a location of the ablative energy output port.

37. Apparatus according to any of claims 1-15 and comprising a catheter having a drill end that is positioned in a neighborhood of or in contact with the region in order to form the hole and wherein the optical output aperture and an acoustic sensor of the at least one acoustic sensor are mounted inside the catheter in a neighborhood of the drill end.

38. Apparatus according to any of claims 35-37 wherein the catheter is configured to perform percutaneous myocardial revascularization.

39. Apparatus according to any of claims 35-37 wherein the catheter is configured to perform transmyocardial revascularization.

40. Apparatus according to any of the preceding claims wherein the at least one acoustic sensor comprises an external acoustic sensor coupled to the patient's skin.

41. Apparatus according to any of claims 1-40 wherein the at least one acoustic sensor comprises an acoustic sensor of an ultrasonic imaging device.

42. Apparatus for forming a hole in a region of the heart muscle wall of a patient undergoing myocardial revascularization comprising:

means for removing tissue from the region to form the hole;

a light source that illuminates the region with light;

an optical sensor that generates signals responsive to light from the light source that is reflected by the region; and

a controller that receives the signals and processes them to determine at least one characteristic of the region useable to control the means for removing tissue.

43. Apparatus according to claim 42 wherein the characteristic is concentration of a substance indicative of viability of tissue in the region.

44. Apparatus according to claim 43 wherein the substance is hemoglobin.

45. Apparatus according to claim 44 wherein the hemoglobin is oxygenated.

46. Apparatus according to claim 43 wherein the substance is cytochrome aa_3 redox.

47. Apparatus according to claim 43 wherein the substance is Hydrogen ions.